Monitoring Protocols and Life-Cycle Costs for Geologic Storage of Carbon Dioxide

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Topics

- Detection limits of monitoring technologies
- Life cycle of a storage project and monitoring requirements
- Monitoring packages
- Monitoring scenarios
- Life cycle monitoring costs
- Implication of long term monitoring
- Conclusions

Potential for Detection Using Seismic Imaging

Scenario	1 Mt CO_2/year			500 MW Power Plant 3.6 Mt CO_2/year		
Leakage Rate (% stored / year)	0.01	0.1	1	0.01	0.1	1
Leakage in 1 year (Mt)	0.0001	0.001	0.01	0.00036	0.0036	0.036
Leakage in 10 years (Mt)	0.0055	0.055	0.55	0.02	0.2	2.0
Leakage in 50 years (Mt)	0.128	1.2	12.8	.46	4.6	46

Myer et al, 2002: 10,000 tonnes

Arts et al., 2004: Sleipner, 4000 tonnes

White el al., 2004: Weyburn, 2500 tonnes

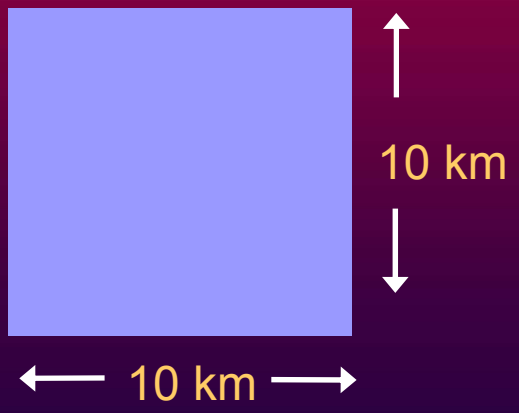
Probable

Possible

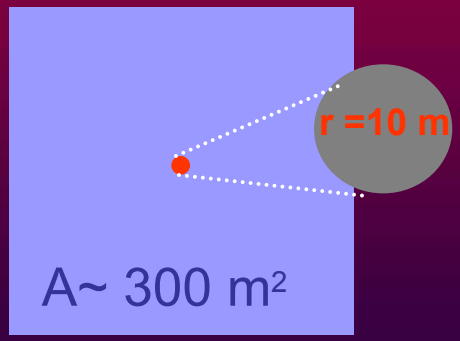
Uncertain

Example Seepage Scenarios

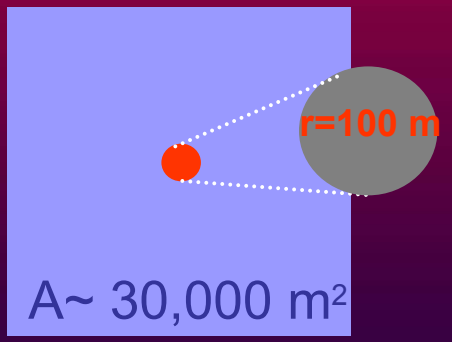
Footprint of CO_2 plume

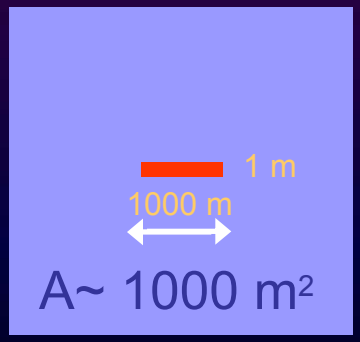


Seepage around a well

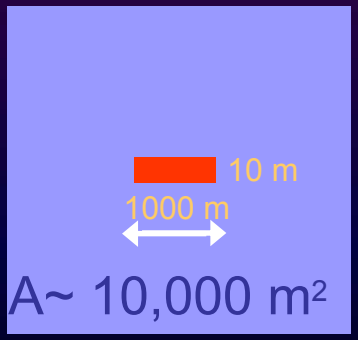


Seepage around a well

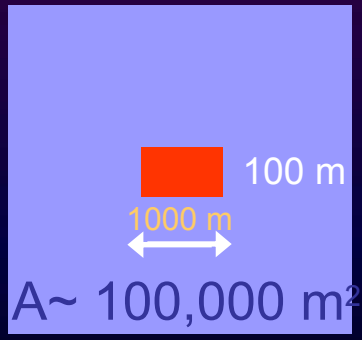




Seepage along a narrow fracture zone

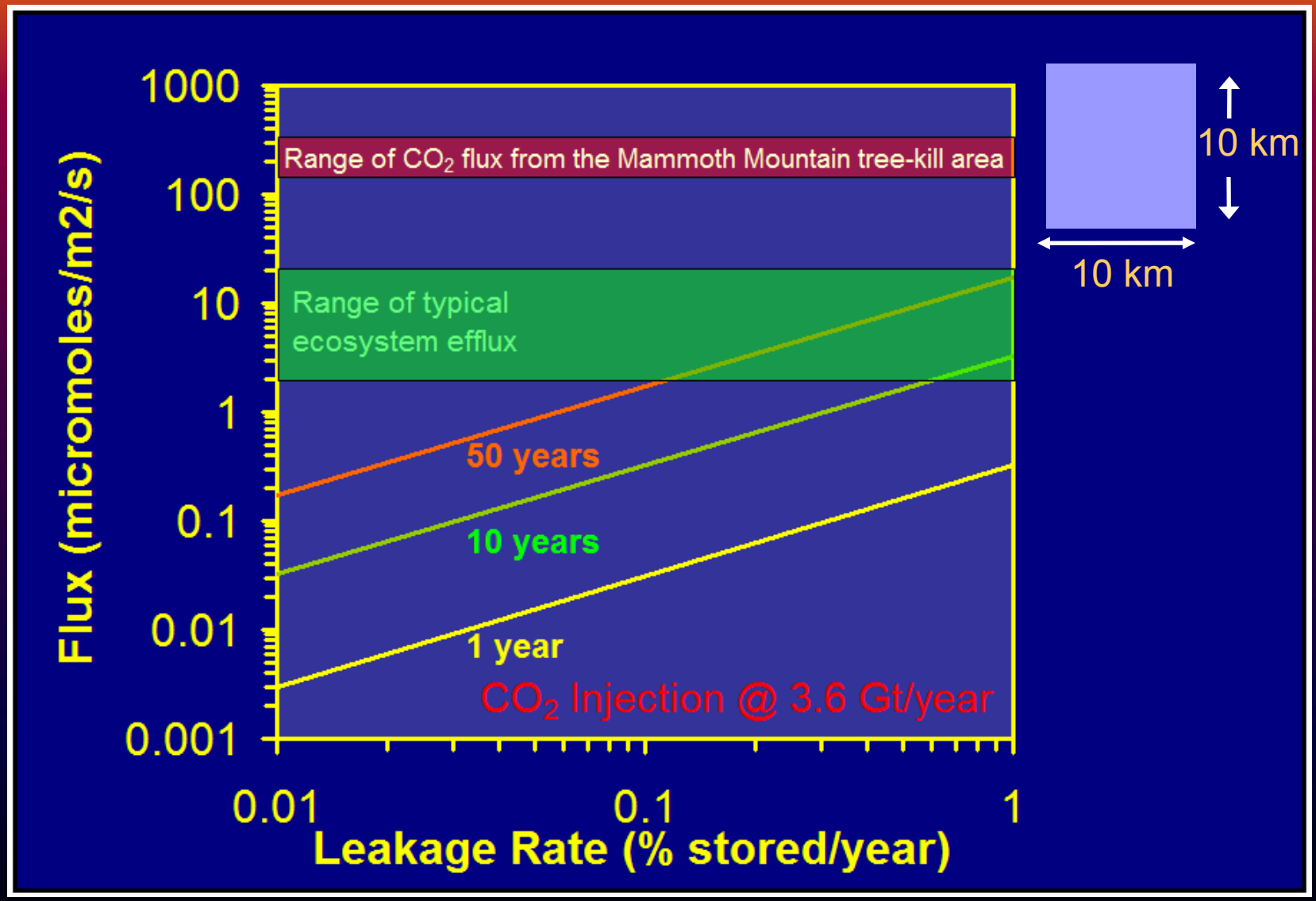


Seepage along a fault zone

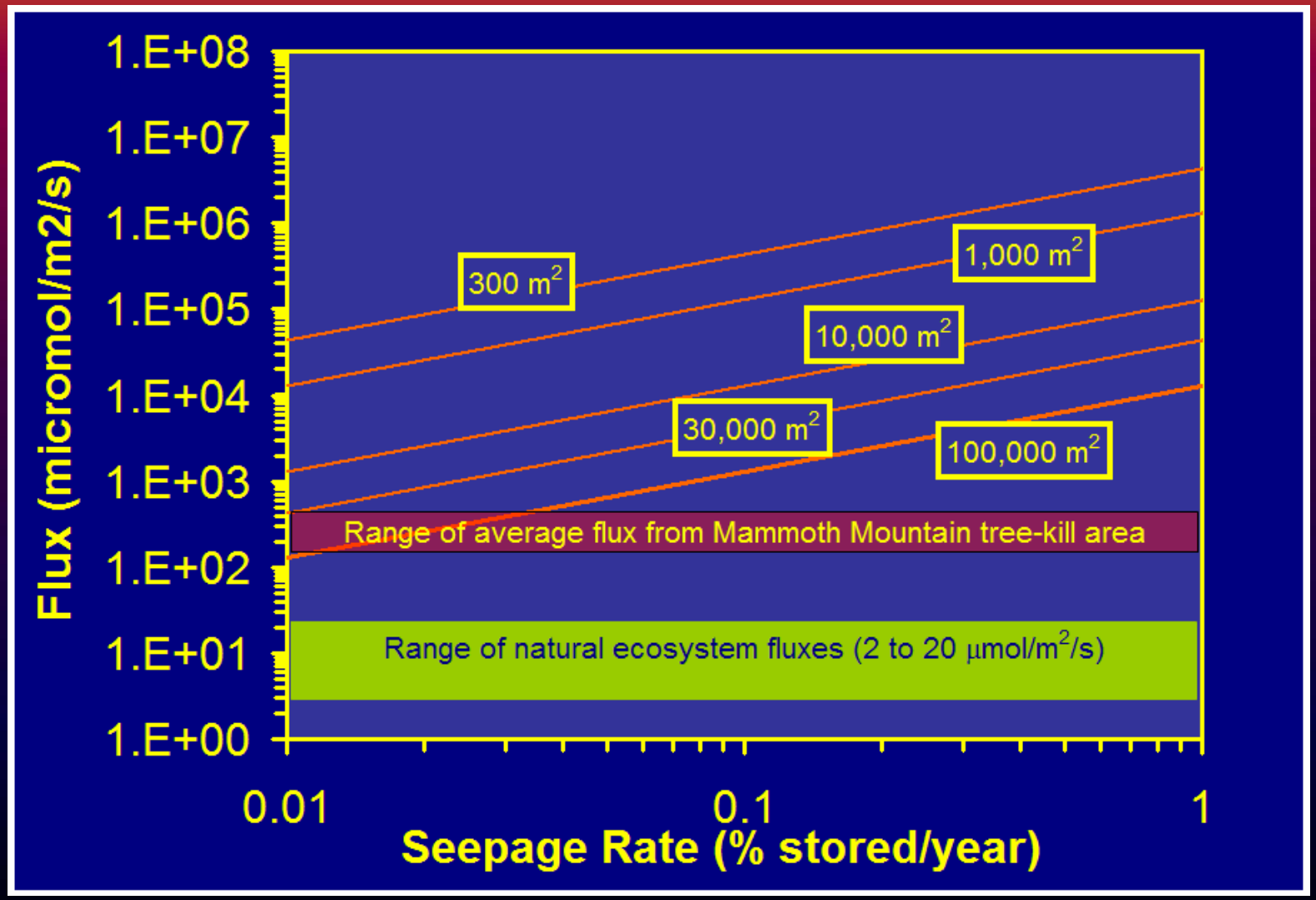


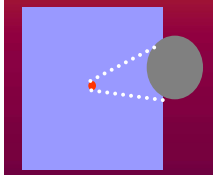
Seepage along a fault zone

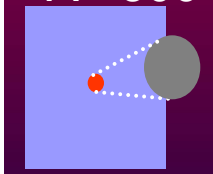
Flux Distributed Over Footprint

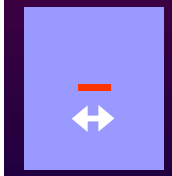


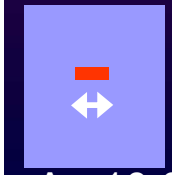
Seepage Fluxes Far Exceed Background

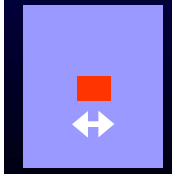



A~ 300 m²

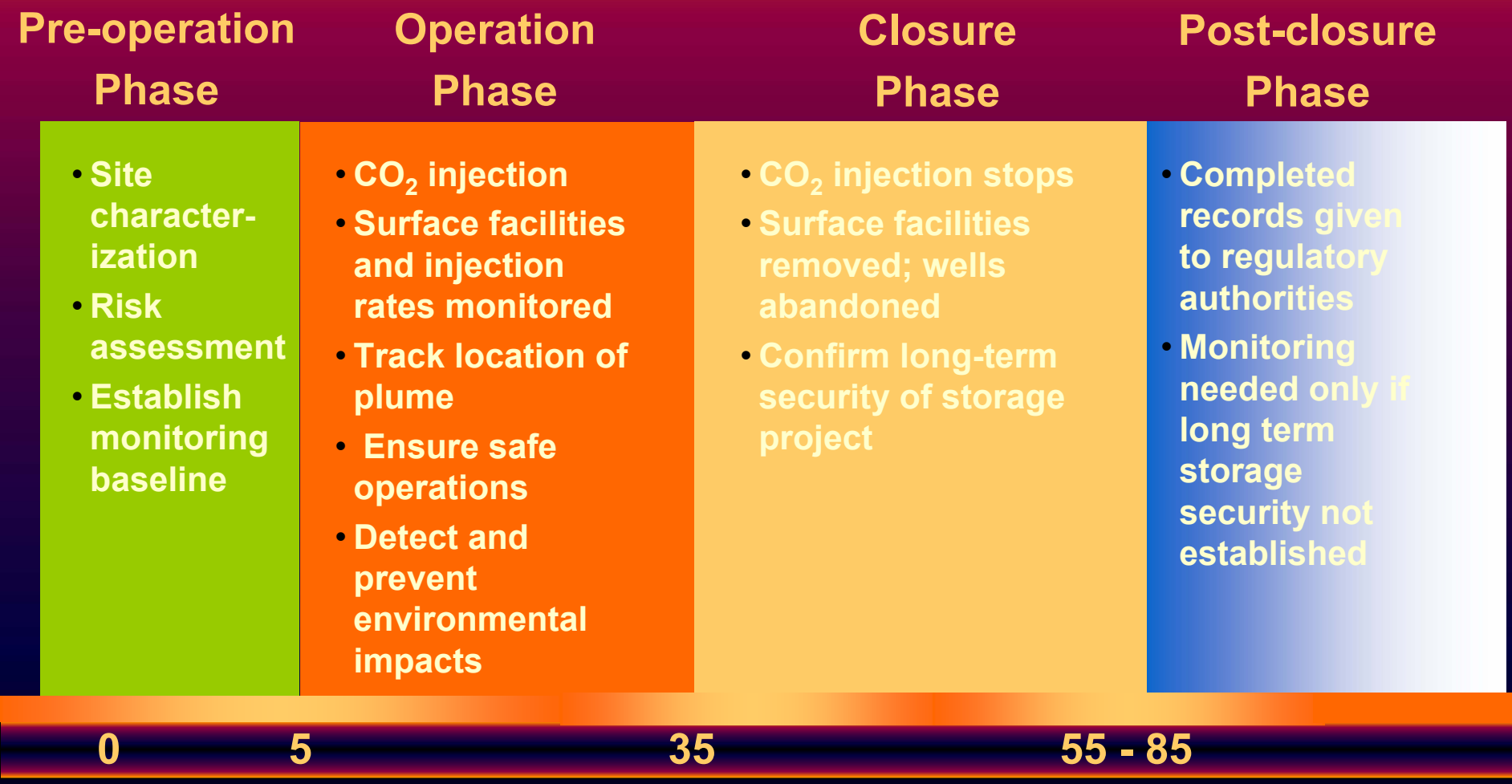

A~ 30,000 m²


A~ 1000 m²


A~ 10,000 m²


A~ 100,000 m²

Life Cycle of a Storage Project and Monitoring Requirements



Components of the Basic and Enhanced Monitoring Packages

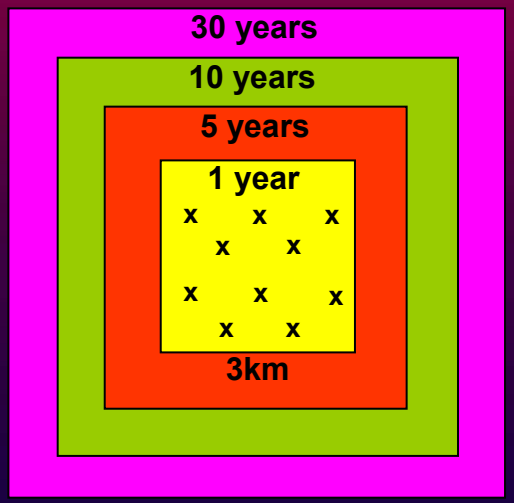
	Basic Monitoring Package	Additional Measurements for Enhanced Monitoring Package
Pre-operational Monitoring	• Well logs • Wellhead pressure • Formation pressure • Injection and production rate testing • Seismic survey • Atmospheric CO_2 monitoring	• Gravity survey • Electromagnetic survey • CO_2 flux monitoring • Pressure and water quality above the storage formation
Operational Monitoring	• Wellhead pressure • Injection and production rates • Wellhead atmospheric CO_2 monitoring • Microseismicity • Seismic surveys	• Well logs • Gravity survey • Electromagnetic survey • Continuous CO_2 flux monitoring at 10 stations • Pressure and water quality above the storage formation
Closure Monitoring	• Seismic survey	• Gravity survey • Electromagnetic survey • Continuous CO_2 flux monitoring at 10 stations • Pressure and water quality above the storage formation • Wellhead pressure monitoring for 5 yeas, after which time the wells will be abandoned

Unit Costs

- Seismic
  - $10,000/km^2 & $1000/km^2 for interpretation
- Gravity and EM (1 station per km^2)
  - $1000 per station
- Surface flux (10 stations)
  - $70,000 set-up per station
  - $10,000 per station for interpretation
- Casing integrity logs
  - $20,000 per injection well per year
- CO_2 concentrations at wellhead
  - $10,000 per well installation
- Microseismicity
  - $40,000 per station & $75,000 per year
- Pressure and groundwater samples above the storage formation
  - $950,000 for well
  - $45,000 for baseline chemistry
  - $5000 for pressure transducer
  - $1,500/sample, taken monthly

Monitoring Scenarios

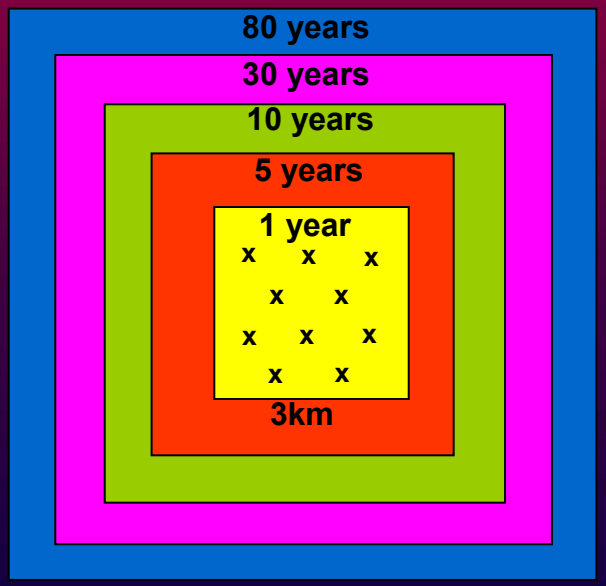
Saline Formation HRG[1]



14 km

50 years
closure monitoring

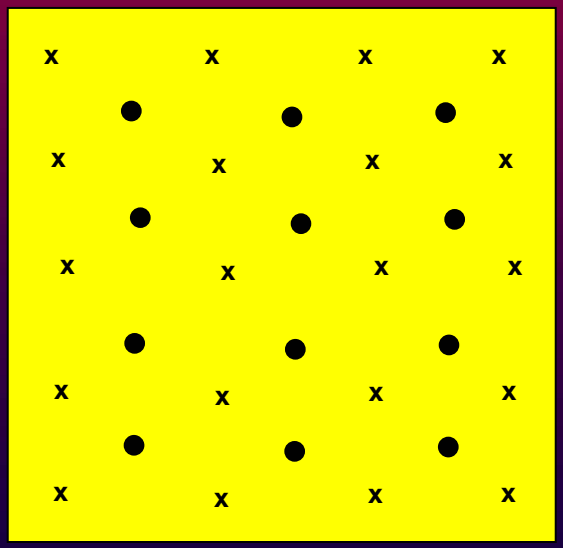
Saline Formation LRG[2]



19 km

50 years
closure monitoring

EOR



18 km

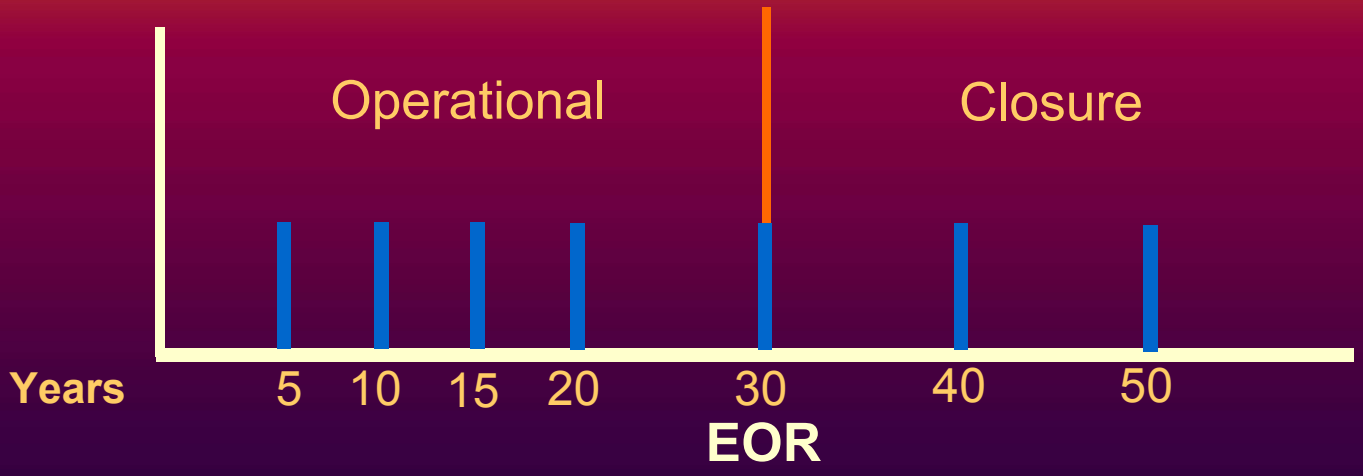
20 years
Closure monitoring

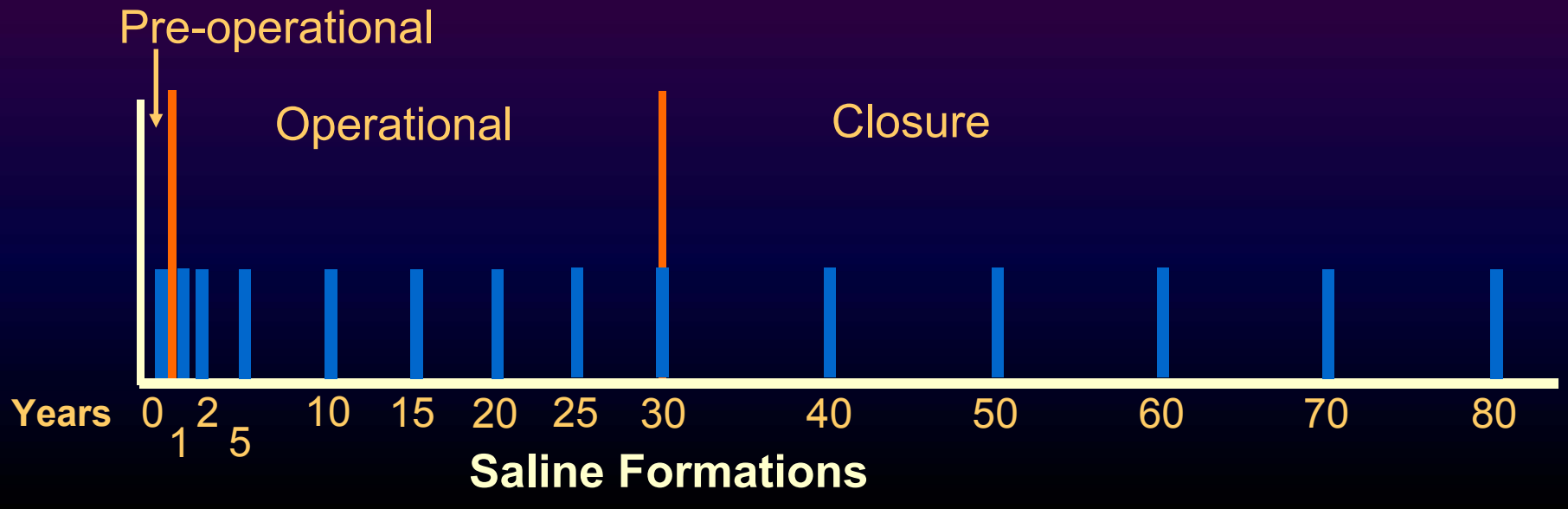
[1] High residual gas saturation

[2] Low residual gas saturation

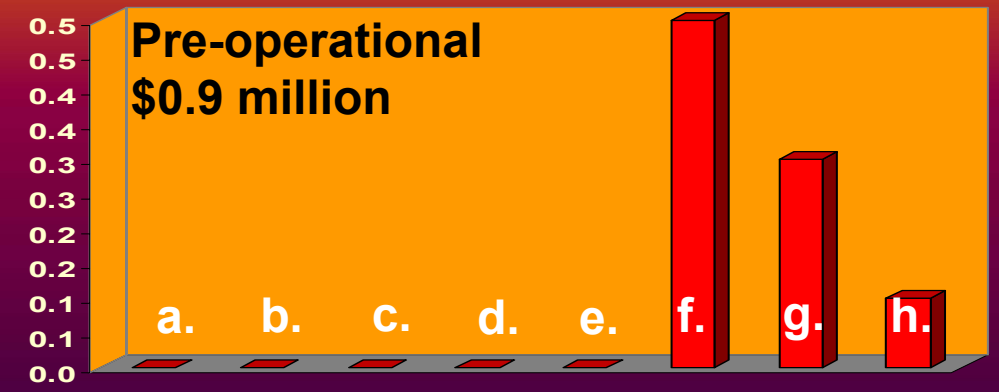
Operational period: 30 years injection @ 8.6 Mt/year totaling 258Mt CO_2

Monitoring Scenarios: Frequency of Geophysical Measurement

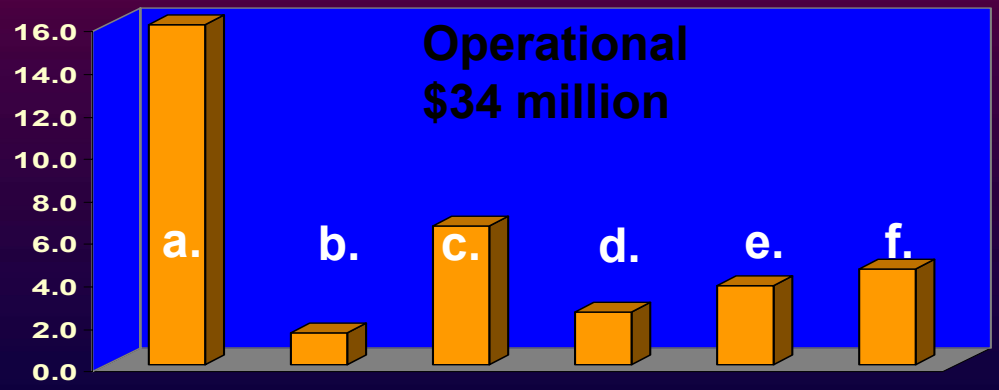




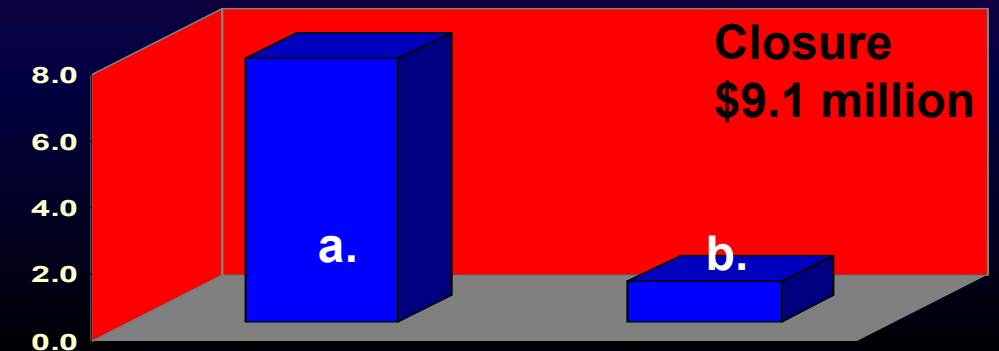
Monitoring Cost for EOR Scenario



a. Well logs
b. Wellhead pressure
c. Formation pressure
d. Injection and production rate testing
e. Seismic survey
f. Microseismicity baseline
g. Baseline atmospheric CO_2 monitoring
h. Management (15%)

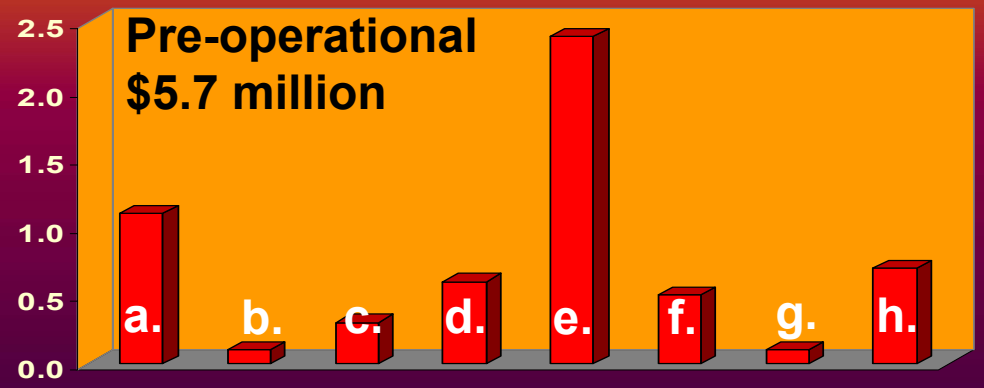


a. Seismic survey
b. Wellhead pressure
c. Injection and production rates
d. Wellhead atmospheric CO_2 concentration
e. Microseismicity
f. Management (15%)



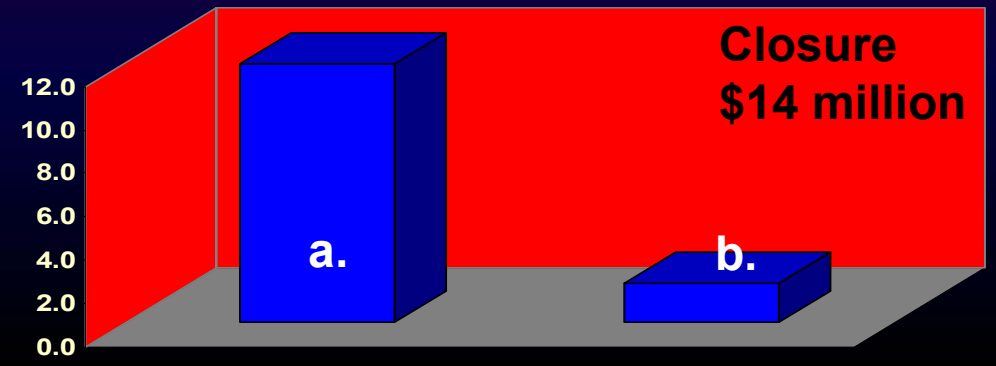
a. Seismic survey
b. Management (15%)

Monitoring Cost for Saline Formation (HRG)



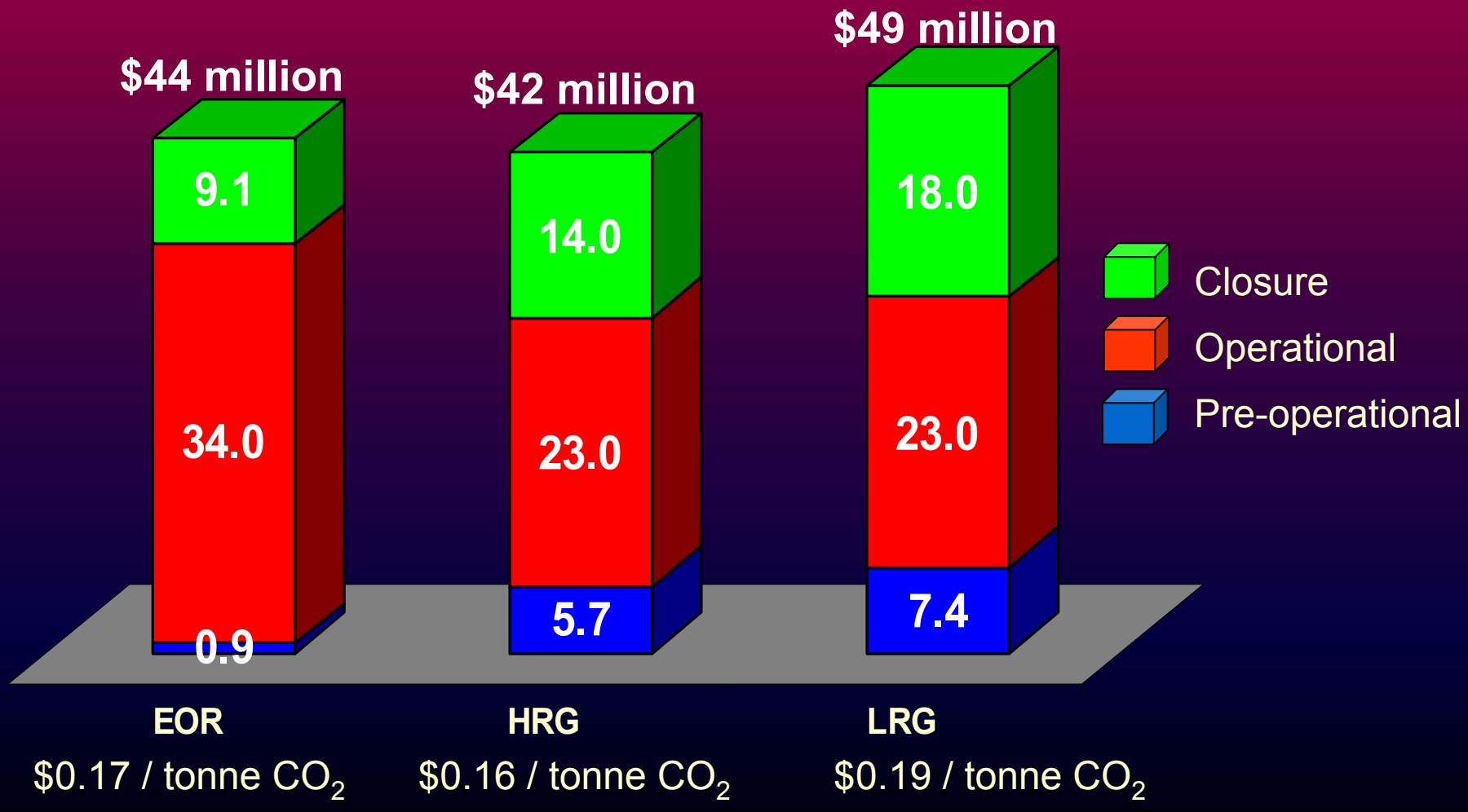
a. Well logs
b. Wellhead pressure
c. Formation pressure
d. Injection and production rate testing
e. Seismic survey
f. Microseismicity baseline
g. Baseline atmospheric CO_2 monitoring
h. Management (15%)

a. Seismic survey
b. Wellhead pressure
c. Injection and production rates
d. Wellhead atmospheric CO_2 concentration
e. Microseismicity
f. Management (15%)

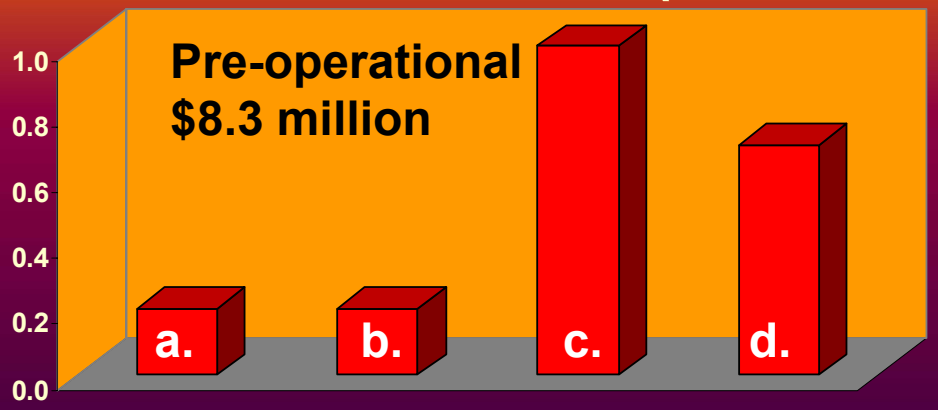


a. Seismic survey
b. Management (15%)

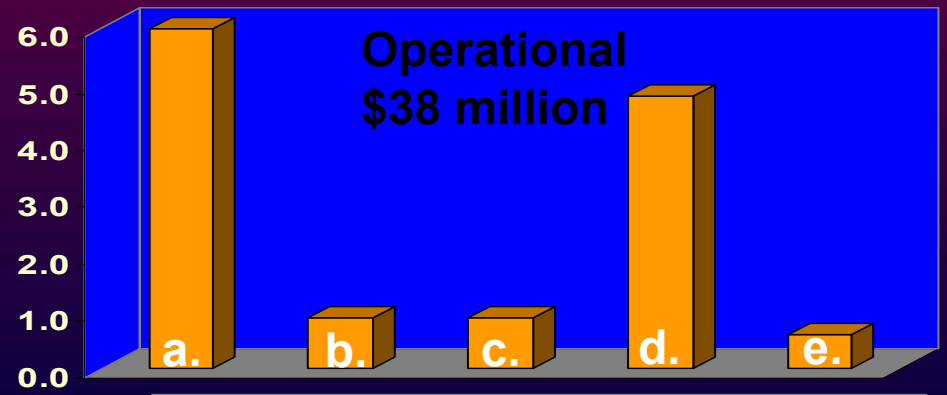
Comparison of Monitoring Costs



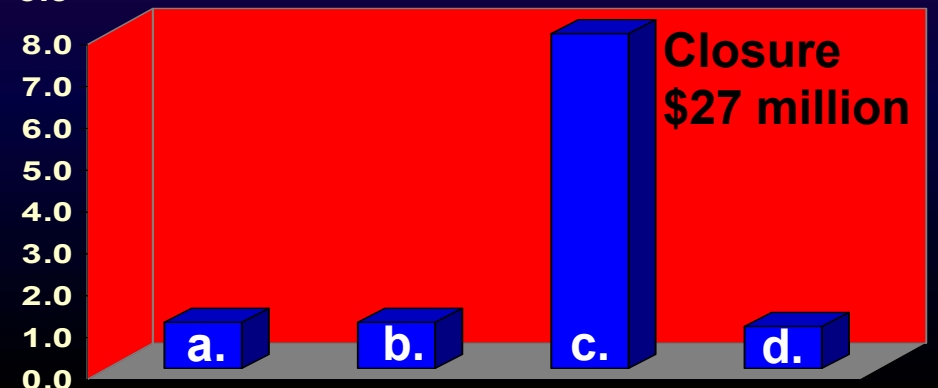
Cost for Enhanced Monitoring Program (Saline HRG)



a. Baseline EM survey
b. Baseline gravity survey
c. Pressure and water quality above the storage formation
d. Baseline CO_2 flux

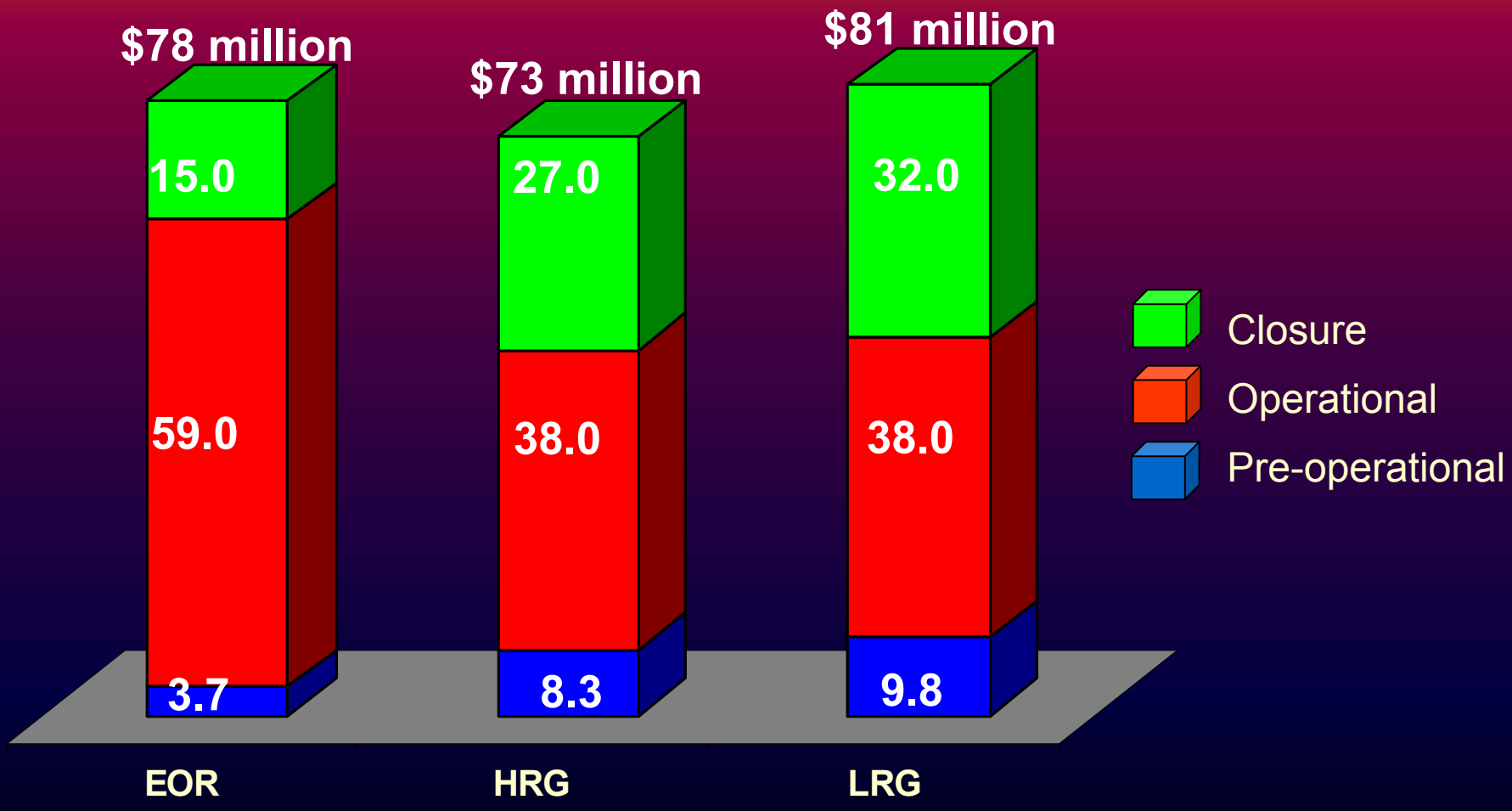


a. Casing integrity logs
b. EM surveys
c. Gravity surveys
d. CO_2 flux monitoring
e. Pressure and water quality above the storage formation

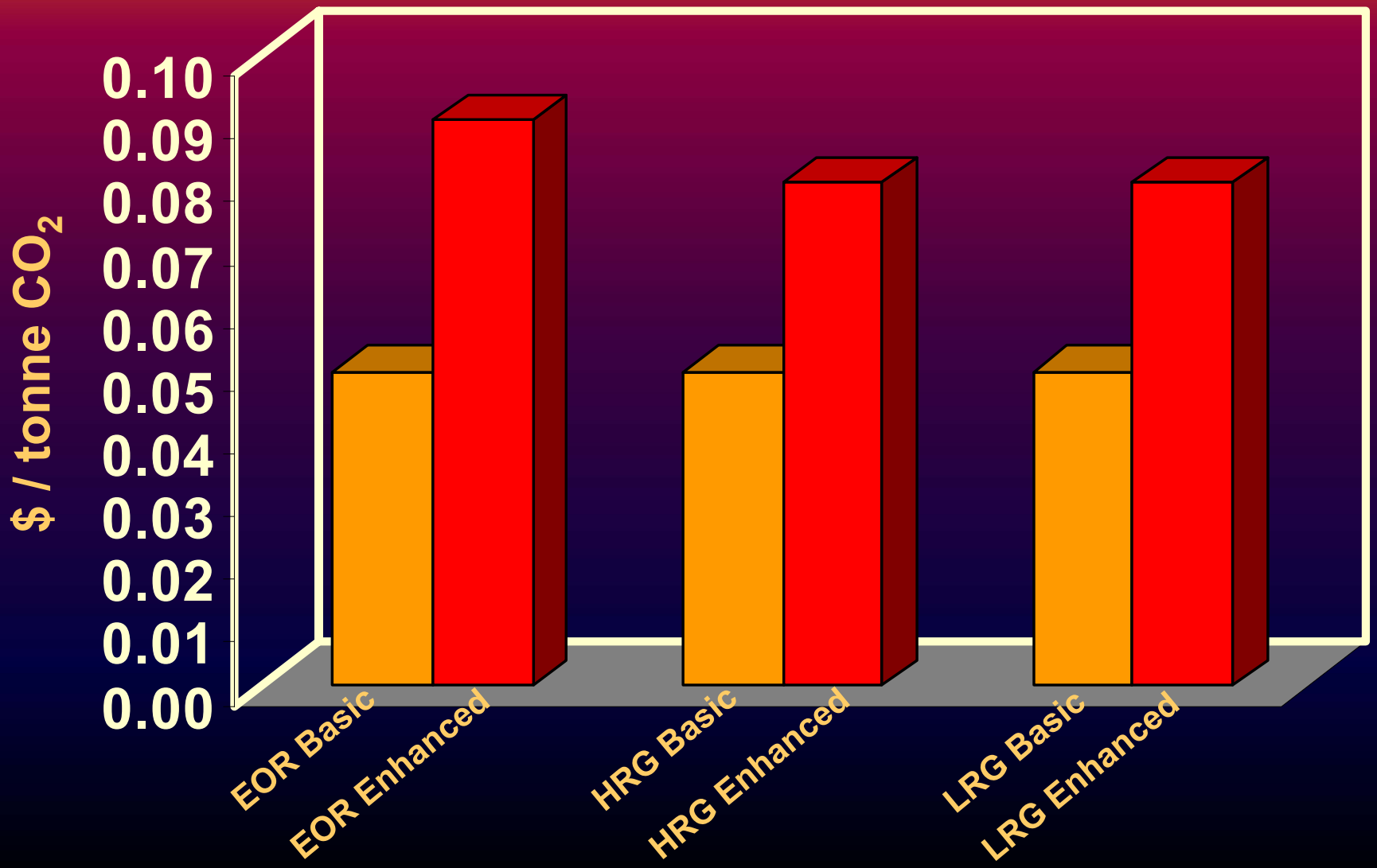


a. EM surveys
b. Gravity surveys
c. CO_2 flux monitoring
d. Pressure and water quality above the storage formation

Comparison of Enhanced Monitoring Costs



Discounted Costs (@10%)



Implications of Longer-term Monitoring

- 1000 year period
- Repeat seismic surveys every 10 years
- Basic monitoring package
  - Intergenerational discount rate of 1% after 30 years
  - $0.053/tonne increases to $0.059/tonne
- 10% increase in cost
- Non-financial issues
  - Responsibility for monitoring
  - Oversight and record keeping
  - Responsibility for remediation

Conclusions

- Discounted costs for monitoring range from \$0.05 to \$0.10 per tonne CO_2
- Enhanced monitoring package available at additional cost of 40-60% over basic package
- Seismic surveys are major cost driver
  - No obvious substitute at this time
  - Sleipner and Weyburn demonstrate effectiveness
- Monitoring is a small part of overall CCS costs (\$30-\$70 per tonne) and storage costs (\$2-\$12 per tonne)